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ScienceDirect

Procedia - Social and Behavioral Sciences 87 (2013) 306 – 320

Procedia
Social and Behavioral Sciences

SIDT Scientific Seminar 2012

Recurring patterns of commercial vehicles movements in urban areas: the Parma case study

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Abstract

Urban freight transport is capable of generating “temporal-related utility” in the urban economy by providing the goods required by the end-consumers at the right time in the right place. This paper focuses on the time sensitivity of one-to-many distribution processes in urban environment. An in-depth 8-month survey of commercial vehicle tours leaving from an urban distribution centre, located in the outskirt of the city of Parma (Italy), has been performed, merging information between a GPS-based dataset and a wider operations dataset. Through continuous approximation models, the relative impact of time-dependent parameters of the delivery process, particularly drivers’ working time and favourite time slots for deliveries, has been analysed along with the effects due to traffic congestion.

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Selection and peer-review under responsibility of SIDT2012 Scientific Committee.

Keywords: City Logistics; Commercial vehicle tours; Congestion; Level of service.

1. Introduction

Urban freight transportation plays a critical role in ensuring the competitiveness and development of urban economies but at the same time it is responsible for the increase in environmental pollution, energy consumption and congestion of urban road networks. In Europe, commercial vehicles movements represent 10 to 15% of vehicle equivalent miles travelled in city streets, which account for 3 to 5% of urban land dedicated to freight transport and logistics (Dablanc, 2010) and contribute for more than 20% in terms of traffic congestion (Schoemaker et al., 2006). An increasing proportion of commercial Vehicle Kilometers Travelled (VKT) in urban areas is due to the fact that the size of stores’ inventory stocks has reduced and businesses have increased their restocking activity frequency based on the just-in-time concept (Browne et al., 2012). According to the results of

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a survey undertaken in 2001 in Milan, the higher replenishment frequency has reduced the daily number of deliveries per vehicle from 30 to 17-18 (Da Rios, Gattuso, 2003). Moreover the number of products sold has considerably increased and stocks change several times a year (Dablanc, 2010).

The resulting high frequency of replenishment operations along with the well-known reluctance of end-consumers to receive shipments outside tight time-windows, have made the distribution operations less efficient and, at the same time, the replenishment process of end-consumers located in urban areas more dependent on the time sensitivity of the activity itself. If the level of service (related to the replenishment activity) provided by the logistic operator and requested by the end-consumer is strongly constrained by its time sensitivity, traffic congestion has to be considered at the same time an external cost related to the Vehicle Kilometers Travelled in urban area by commercial vehicles and a crucial factor affecting the efficiency of the delivery process through increased travel times and uncertainty due to travel time variability.

The scientific literature in this field is vast, especially that on modeling issues (for example, Nuzzolo, Crisalli, & Comi 2013, Polimeni & Vitetta 2013, Ruan, Lin, & Kawamura 2012, Anand, Quak, Van Duin, & Tavasszy, 2012). The paper focuses on the efficiency of one-to-many distribution processes in urban environment (a typical depot located in the outskirt of the service area that provides to several retailers or customers) and its application on a city with a premium built environment, Parma (Italy), with a maze of narrow streets and plenty of landmarks, and the mutual interrelation among typical features: the urban environment, end-consumers typical behaviours, operational issues, and road traffic congestion. The one-to-many configuration has been chosen because a number of studies (from Europe and United States) have shown that deliveries from a warehouse have a very large impact on VKT in urban areas (Outwater et al., 2005; STA, 2000, CITYPORTS, 2005; Cambridge Systematics, 2003); moreover, this is in line with the several examples of Urban Distributions Centres (UDC) operational in Italy (Siena, Vicenza, Modena).

All of the assumptions regarding the properties and binding constraints of commercial delivery tours in urban areas, derived from the real-world data analyses, have been assumed as a starting point to analytically model, through the proposed methodology, trip chain structure and estimate the relevance of specific temporal constraints in the overall operations management.

2. The Methodology

In this paper, approximations to the distance travelled by a fleet of commercial vehicles in a service area, are based on simple formulas derived through continuous approximation models and applied to the Parma UDC case study. Estimations of the average length of Vehicle Routing Problems (VRPs), based on continuous approximation models, have been successfully applied in the extant literature to provide strategic analyses of delivery operations and capture their performance. In such problems, dealing with a distribution centre serving an area with variations in demand, average distances travelled are estimated as a function of the number of customers to be served and the number of tours needed to meet their requests. As a matter of fact, the distance travelled is a key parameter to assess the process efficiency from the logistic operator's perspective and also to solve problems dealing with facility locations, fleets size and networks design.

A relevant contribution to the analysis of the effects of routing constraints (vehicle capacity, length of the workday, service-level targets, etc) in affecting the number and characteristics of the feasible set of tours that carriers can use to meet the customer demand, was established by Figliozzi (2007). Figliozzi proposed a tour classification based on supply chain characteristics and route constraints and, using a model based on Daganzo's approximations to routing problems, analytically derived that changes in both VKT and Vehicle Hours Travelled (VHT) can be strongly affected by the tour type. Intuitions about the impacts of network/logistics changes

(increase in congestion, shipment size and delivery frequency variability, etc..) and policy implications (limitations to the free circulation of commercial vehicles, restrictions on commercial vehicle parking, etc...) on VKT are accordingly derived.

Sankaran and Wood (2007) presented continuous approximation models seeking to capture the relative impact of relevant dimensions of consignee behaviour, particularly Just-in-time (JIT) replenishment, the duration of the workday and traffic congestion on distribution costs. They indicated that congestion costs increase with the average number of tours per day and decrease with the workday duration.

Figliozzi (2010) analysed the impact of congestion on commercial vehicle tour through a simple and intuitive formula based again on Daganzo's approximation routing problems. The sensitivity analysis based on a real-world situation (assuming as service area the industrial district of Bankstown in the city of Sidney, Australia) and tour data reported from the literature, showed that long distance between the depot and the customer(s) to serve exacerbates the negative impacts of congestion; moreover, travel time variability is not a significant variable when the travel time between the depot and customers is small in relation to the maximum tour duration and when tours are not highly constrained.

Coherently with all of the above, this paper focuses on a system with one depot and n customers to be served. A tour is defined as the path that a truck follows from its depot to visit one or more customers in a sequence before returning to its depot during a single driver shift. The mathematical expression used in this research to approximate the distance travelled to serve the customers located in the service area $l(n)$, taking into consideration the number of customers, the proximity among the customers and the proximity of the storage facility to the customers, is:

$$l(n) = k_z z + k_l \sqrt{an} + k_b \sqrt{a/n} \quad (1)$$

where z is the number of tours needed to serve the n customers, a is the extent of the service area and k_z , k_l and k_b are parameters that have been estimated by regression and mainly depending on the depot location, routing constraints, and spatial distribution of customers. Expression (1) can be interpreted as having: the first term representing the connecting distance from the UDC to the service area, the second term accounting for the local tour distance travelled in the Travelling Salesman Tour (TST) for reaching the end-consumers and the last term can be assumed as the bridging distance between them. Expression (1) has been derived by Figliozzi (2008), using Daganzo's continuous approximation models applied to routing and distribution problems (1991), and it has proven to be a more robust approximation to predict the length of VRPs in real urban network and in randomly generated problems.

In this study, expression (1) has been modified assuming the term $(n - z)/n$ to approximate the length of the local tour, as follows:

$$l(n) = k_z z + k_l \frac{n - z}{n} \sqrt{an} + k_b \sqrt{a/n} \quad (2)$$

The theoretical and intuitive properties of this term, in adjusting the accuracy of the tour length estimation as a function of n and z , have been already tested (Figliozzi, 2008); moreover better performance in terms of prediction accuracy have been obtained applying expression (2) to the Parma case study: the regression fit is high with a $R^2 > 0,98$, a Mean Absolute Percentage Error (MAPE) of less than 6,0%, and a Mean Percentage Error (MPE) of -1,0%. The MAPE represents the average deviation between the actual tours length and the estimated

one, as a percentage of the actual distance traveled, and the MPE shows if the estimated tours length is higher or lower the actual one.

Assuming expression (2) as an approximation to the length of vehicle routing problems to reach n customers, the numbers of retailers served per tour can increase or decrease in order to meet the routing constraints (vehicle capacity, drivers' working time, favored time windows for deliveries), according to possible exogenous factors, typically travel time variability due to congestion. A common assumption when continuous approximations are utilized is that routes are balanced, i.e. routes have a similar number of customers (Daganzo, 1991). Assuming balanced routes, the binding constraint for each route with an average of n/z customers can be expressed as:

$$\frac{1}{s} \left(k_z + \frac{k_l}{z} \frac{n-z}{n} \sqrt{an} + \frac{k_b}{z} \sqrt{\frac{a}{n}} \right) + \frac{n}{z} t_c \leq w \quad (3)$$

let:

\bar{s} : average travel speed on the network

t_c : the service time when stopping at the retailer (end-consumer);

w : the effective drivers' working time;

An increase in average travel time can be expressed by the congestion increase coefficient $\alpha \geq 1$ which reflects the increase in average travel times on the road network with respect to the free-flow condition, as follows:

$$\bar{s} = \frac{s^f}{\alpha} \quad (4)$$

If the travel times are not constant, the buffer $\sigma_r^* \zeta$ must be added to the right-hand term of expression (3) in order to guarantee the customer service level, where σ_r is the route travel time standard deviation and ζ is the coefficient related to the probability of completing the tour within the allowed tour duration, assuming normally distributed travel times.

By using the above described coefficients, expression (3) becomes:

$$\frac{\alpha}{s^f} \left(k_z + \frac{k_l}{z} \frac{n-z}{n} \sqrt{an} + \frac{k_b}{z} \sqrt{\frac{a}{n}} \right) + \frac{n}{z} t_c \leq \rho w - \sigma_r \zeta \quad (5)$$

Where ρ is the time windows factor, i.e. the ratio between the time window length for delivery and the working shift length (w).

An increase in congestion will reduce the average travel speed and affect the travel time variability; as a consequence, if the tour duration constraint is violated, to restore feasibility the number of tours needed for satisfying the customers' requests must be increased and the average number of stops per tour must be decreased. The impact on the efficiency of tours is significant, since the binding temporal constraint not only reduces the proportion of time available for accomplishing the average delivery tour but also decreases the density of customers per tour.

3. The case of Parma

The pre-requisite for studying one-to-many distribution processes in urban areas is the availability of disaggregated data on operations run by a given distribution company and a local platform in charge of last-mile pick-up and delivery operations. This is a critical issue due to the operators' well-known reluctance to provide information and it also explains why analyses of the properties of urban freight tours, in relation to their efficiency and contribution to VKT, do not abound in the scientific literature. This is not the case of this study, which relied on the data supplied by the local Urban Distribution Center (UDC), operating across the Parma urban area since April, 2008.

The UDC is located in the city outskirts, 2km-far from the ring road which surrounds the city center (Figure 1, with poorly accessible areas, in red, according to the average speed values estimated on the observed UDC-customers routes): a 2.6 sqkm area with about 21,000 inhabitants. Parma UDC is part of a more ambitious plan for the reorganization of the local logistics processes called Ecologistics, which envisages the use of low-emission vehicles for delivery operations and the enforcement of restriction policies to regulate the access of commercial vehicles to the city central area. The need to manage the access to the central area comes from the sensitiveness due to its built environment, mostly developed between the XIV-XVII centuries; this called, since the 1990's, for a specific preservation policy which turned the area into a "Zone of High Urban Relevance": a non-motorized realm (being bicycles since ever one of the most popular mode), with an access restriction for private vehicles.



Fig. 1. The study area

3.1. Data set

The study relied on two different data sets: the so-called Shipments Dataset and Tours Dataset. The former is dealing with the data concerning each single shipment operated by the UDC from January to August 2011, including origin and destination, shipment size and number of parcels, the latter provides a set of detailed information concerning tour operations from January to August 2011 as well, thanks to the availability of GPS-

based data collected directly on-board. Both datasets have been made available by the UDC as MS Excel spreadsheets.

After having removed the tours for which the loss or degradation of GPS data could compromise the accuracy of the analysis, the study was focused on a sample of 2,595 tours, corresponding to 22,700 trips and 19,582 deliveries, operated across an area wider than the municipal one; the localization of many customers beyond the municipal borders is due to the fact that the UDC belongs to a major facility, the Centro Agro Alimentare and Logistic of Parma (C.A.L.) which concentrates the main business of the local fruit and vegetable markets.

Each tour operated to reach the n -customers has been disaggregated into three consecutive phases, each corresponding to travelled kilometres for:

1. Reaching the first customer from the UDC;
2. Reaching the remaining $n-1$ customers within the service area;
3. Reaching back the UDC.

For each phase information concerning the origin and destination as well as the departure and arrival times are available. Phase 2, on its turn, is divided into the $n-1$ trips travelled, for which origin and destination and the departure and arrival times are available, as well. After having analyzed all of the above for a given tour, it is possible to assess some parameters typical of the urban logistics process, more specifically:

- The average speed per single trip (both within and outside the service area)
- The percentage of driving and stop times
- The journey back to the UDC and the related travel time
- The occupancy rate per tour.

Merging information from the available datasets, each shipment can be listed both per single trip (as the journey between two deliveries) and per single tour (as the whole journey, from the moment the vehicle egress the UDC to the one the vehicle access it, at the end of the planned operations). An example of the truck activity analysis provided per tour is reported in Table 1.

Table 1. An example of tour analysis

	address	time (h:m)	trip distance (km)	trip travel time (min)	average speed (km/h)	stop time (min)	number of parcels (units)
UDC	Strada del Taglio, 5	07:49					
1° customer	Strada Garibaldi, 2	8:00 – 8:14	4.2	11	22.91	14	4
2° customer	Via Mazzolari, 30	8:24 – 8:34	4.6	10	27.6	10	2
3° customer	Via Guercino, 5	8:41 – 9:01	1.2	7	10.29	20	27
4° customer	Borgo Bernabei, 7	9:18 – 9:33	3.4	17	12.00	15	13
UDC	Strada del Taglio, 5	9:43	3.0	10	18.00		

4. The tour classes

The whole available datasets (2,595 tours) is characterised by a significant variability in terms of tours parameters (mostly tour length and tour travel time), due to the above mentioned localization of many customers beyond the municipal borders. Useful insights regarding the efficiency of commercial delivery tours can be obtained considering the correlation between the percentage of driving time per tour and the average distance travelled per customer (Figliozi, 2010). Since the percentage of driving time is not directly related to the total

tour duration or the total distance travelled, such a parameter can be usefully applied to the Parma case study to provide a general tour analysis, because of the above mentioned variability (Figure 2).

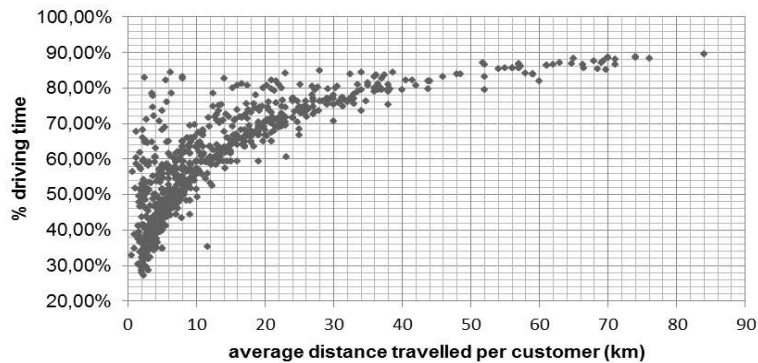


Fig. 2. Tour analysis by percentage of driving time and distance travelled per customer

Tours reported on the lower left section of the graph seem to be extremely efficient from the logistic operator's perspective as they serve, on average, many customers located nearby the UDC and close to each others; consequently a low percentage of the tour duration is spent driving on the road. On the upper right section of the graph, tours have fewer stops and customers are, on average, located further away from the UDC; as a result, a high percentage of the tour time is spent to reach, from the facility, the area where the customers are located.

The analysis above described suggests interpreting the characteristic of the local distribution operations in terms of UDC-customer distances; as a matter of fact, the analyzed tours can be divided into three classes, according to the surveyed distance between the facility and each customer to serve and the size of the whole urban area:

- Class I: tours with UDC-customer distance < 10 km, also called Urban Tours
- Class II: tours with UDC-customer distance between 10 and 20 km
- Class III: tours with UDC-customer distance > 20 km

Consequently, the main features of each Class can be highlighted by the data reported in Table 2. The average value of the travelled kms per delivery (or stop) for Class I is virtually four times lower than that of Class III. Since it is generally acknowledged that the longer the distance, the higher the costs of operations and therefore the more time spent per single delivery, in this case such relationship highlights that Urban Tours (i.e. those of Class I) seem to be the most efficient, also if the modest variation of the amount of deliveries per tour among the three Classes is considered.

Table 2. Characteristics of the tours classes

	Class I (distance <10 km)	Class II (distance >10 km and <20 km)	Class III (distance >20 km)
Distance travelled per delivery (km)	4.6	9.2	17.8
Deliveries per tour (unit)	4.5	4.8	5.5
Occupancy rate (%)	29.9	44.7	56.7
Direct deliveries/all deliveries (%)	23.5	27.8	10.5
Empty distance per tour (%)	38.5	39.2	22.5

However, Urban Tours, although characterized by shorter distances, are affected by exogenous and endogenous constraints which prevent operators from optimizing occupancy and routes, as the Class I occupancy rate clearly demonstrates. This does not reach 30%, whereas those of Classes II and III are much higher, respectively 44.7% and 56.7%; Class I occupancy rate becomes even more significant if the relevance of the direct deliveries (i.e. no stops in between the UDC and end-consumer) is considered: about one every four deliveries within a 10km distance is direct.

This means that, in this case, to the increase of the percentage of direct deliveries does not correspond an increase in the occupancy of the vehicles, as on the contrary it has to be expected if the overall efficiency of the distribution process is to be achieved. The possibility to operate direct deliveries seems, therefore, not linked to occupancy constraints but to those of the levels of service: the typical end-consumer requires to be supplied by small amounts of parcels, rather frequently and, above all, within given time windows. Such requirements become stricter in urban areas, such as that of Parma, with very mixed land use and premium built environment, which often means both the sprawl across the whole central area of a high number of small size retail facilities, with even smaller or virtually no storage areas, and the increasing demand for the just-in-time management of supplies.

5. The Urban Tours analysis

As a matter of fact, Urban Tours (or Class I Tours) accounted for about 45% of the 2,595 tours surveyed over the 8-month period, serving 607 end-consumers, for a total of 3,456 trips operated by a fleet of 11 commercial vehicles (respectively: 6, 1.6 ton methane-fuelled and 5, 2.2 ton gasoil-fuelled). Each end-consumer served by an Urban Tour received, in average, 5 parcels per delivery (corresponding to 49 kg), a small amount if compared to the average of the three Classes (13 parcels per delivery, corresponding to 161 kg); a result consistent with the sensitiveness of the area, above mentioned.

The real-world data analysis on Urban Tours stressed the relevance of temporal constraints in the overall operations management, which was synthesized according to three main parameters: frequency of replenishment; temporal distribution of deliveries (and deliveries time slots); and travel speed variability.

5.1. The frequency of replenishment

The overall analysis of the frequency of replenishment, based on the monthly distribution of operations in terms of minimum and maximum interval between two consecutive deliveries, pointed out a very clear behaviour (Figure 3): only about 7% of end-consumers have goods delivered several times per day, but about 24% of them concentrate the deliveries strictly on one day and the next and for about 44% of them the minimum interval between two consecutive deliveries is less than 3 days; at the same time, about one end-consumers every four (24%) receive goods on a weekly basis at the latest.

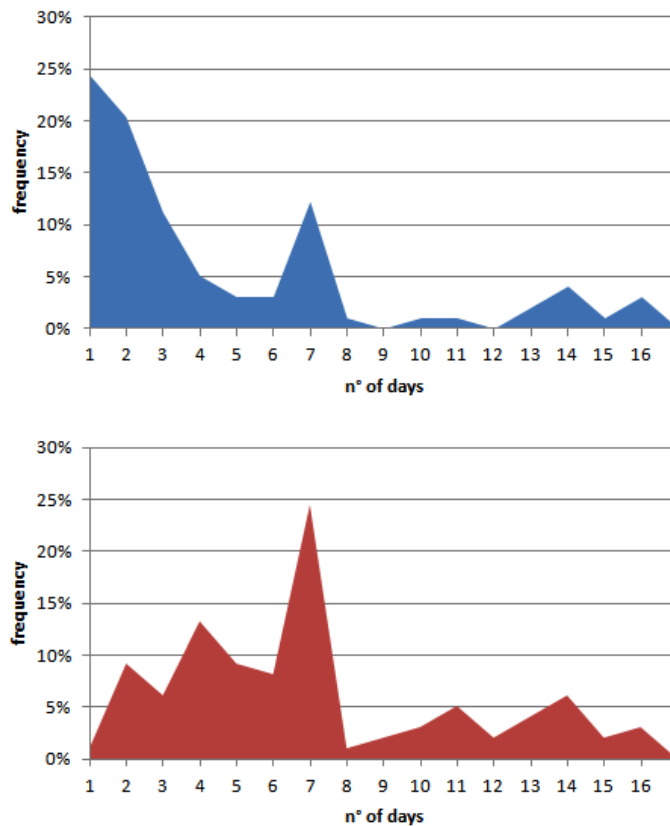


Fig. 3. Frequency of deliveries: minimum (above) and maximum (below) interval between two consecutives deliveries

5.2. The temporal distribution of deliveries

Needless to say, also in the case of Parma, the deliveries timeframe stressed strong peak phenomena, typical of urban areas (Figure 4). More specifically, about 46% of the surveyed deliveries occurred from 8 to 10 am, with a 31% peak between 8 and 9 am. Afternoon (2 - 7 pm) can be considered the off-peak time, with much smaller percentage of deliveries (between 3.8 and 5.8 %). To describe the peak time in other words, it suffices to say that 74% of retailers have goods delivered in the morning time.

It is also worth stressing that virtually no deliveries occur outside the business times (which is usually from 9 am to 1 pm and from 2 to 7 pm), being only 2.9% of deliveries recorded before 8 am and just 0.5% after 7 pm or during the lunch break. This is mainly due to the retailers' reluctance to afford extra business hours just to receive goods, although commercial vehicles from the UDC are permitted to enter the central area from 6 am to 10 pm.

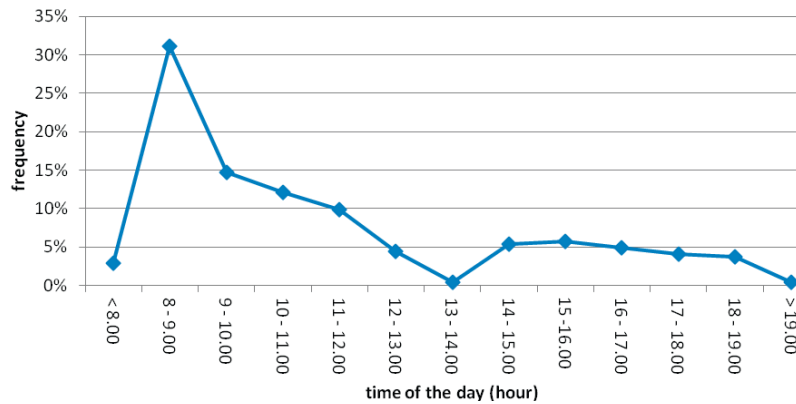


Fig. 4. Temporal distribution of deliveries

Time distribution of deliveries has been also analyzed according to the types of goods delivered/facility served (Figure 5).

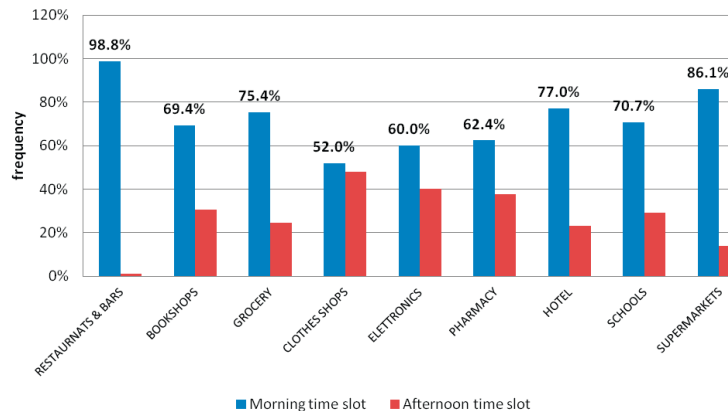


Fig. 5. Deliveries time slots distribution

The only category which is, virtually, equally served in both morning and afternoon slots is the clothing one (52% in the morning and 48 % in the afternoon); in this trend, although at a lower level, can be included pharmacies and electronics retail stores. On the contrary, the food delivery seems to be a morning-only business, as the percentages of restaurants/eateries/coffee shops and supermarkets demonstrate (respectively 98.8% and 86%); Ho.Re.Ca. seems to be a little more flexible (77%).

5.3. The travel speed variability

A reciprocal relationship was observed between the variability of travel times and the traffic peak/off-peak phenomena for Urban Tours, even more significant if compared to that for tours of Class III (Table 3).

Table 3. Speed Average, Standard Deviation and Coefficient of Variation per departure time and tour class

	6.00 – 8.00	8.00 – 10.00	10.00 – 12.00	12.00 – 14.00	14.00 – 16.00	16.00 – 18.00	18.00 – 20.00
Class I Tour							
Average Speed (km/h)	23.09	18.97	19.83	21.18	19.74	19.26	22.79
Speed Standard Deviation	4.00	7.01	7.37	6.18	7.05	8.24	5.91
Speed Coefficient of Variation	0.17	0.37	0.37	0.31	0.36	0.43	0.26
Class III Tour							
Average Speed (km/h)	30.01	31.73	32.92	32.83	32.88	33.92	29.98
Speed Standard Deviation	6.74	9.46	8.11	7.46	7.67	9.40	7.06
Speed Coefficient of Variation	0.22	0.30	0.25	0.23	0.23	0.28	0.23

The average speed for Urban Tours is the lowest: 20.7 km/h vs 32 km/h recorded for Class III tours, which is not surprising, since the majority of roads within the city centre are local, with very narrow carriageways. The strongest speed reductions for Urban Tours occur during the morning (8 – 10 am) and afternoon (4 – 6 pm) peak hours, thus coinciding with the majority of home-to-work and home-to-school journeys within the central area; similarly, reductions for Class III are registered respectively earlier in the morning (6 – 8 am) and later in the afternoon (6 – 8 pm), thus coinciding with the major flows accessing and egressing the urban area. The Standard Deviation analysis stresses that the longest tours are also the most variable ones, probably reflecting the variety of the infrastructures (from the narrow alleyways of the city center to the more modern highways of the outskirts). Finally, the coefficient of variation, ratio of the standard deviation to the average speed, shows higher average values for Urban Tours, which seem to be subject to more speed variation during the whole day.

5.4. The time-sensitivity analysis

The analytical approach described in section 2 has been applied to the UDC's truck activity records (stored in the Tour Dataset) as regard to the Urban Tours, to provide a sensitivity analysis dealing with temporal-related parameters and assess how congestion and temporal routing constraints affect the tours efficiency from the distributor perspective. Expression (5) has been used to assess how the interactive effect between temporal constraints affecting the tours maximum travel times along with an increase in travel time and travel time variability due to congestion can affect the tour optimization. Since congestion reduces the ability to serve customers per working shift or favoured delivery time slot, the impact on travel time alone is not enough to describe the implications on the efficiency of logistics operations, and the distance travelled to serve a given set of end-consumers requests must also be considered.

The effect due to the increase in travel time variability has been considered through the introduction of the coefficient of variation (v). Although in practice commercial vehicles do not experience the same levels of travel time variability at all points in a route, a constant coefficient of variation is assumed for the sake of simplicity. Assuming a constant coefficient of variation in route r , the route travel time standard deviation (σ_r) can be expressed as:

$$\sigma_r = v \alpha \sigma_r^f = v \alpha \sqrt{\sum_{k \in L_r} (t_k^f)^2} \quad (6)$$

Where:

v : the travel time coefficient of variation;

α : the congestion increase coefficient;

σ_f : the free-flow standard deviation of the route travel time;

t_k : the free-flow travel time on the link k , $\forall k \in r$.

By using expression (6) in expression (5), the multiplicative impact of tour duration constraints and traffic congestion on the road network, dealing with increased travel times and uncertainty due to travel time variability, has been analytically elaborated.

On a quality level, an increase in congestion would affect both the average time to complete the tour, through the effect of the congestion increase coefficient ($\alpha \geq 1$) on the left-hand term of expression (5), and the tour duration constraint, through the buffer $\sigma_r^* \zeta$ in the right-hand term of the same inequality, since the route travel time standard deviation can be formulated as in expression (6).

A tour starts at the UDC, visits 2, 5 or 8 customers and then returns to the facility. The sensitivity analysis assumes as relevant parameters the congestion increase coefficient (α), the travel time coefficient of variation (v) and the tour duration constraint (pw). The reduction in travel speed with respect to free-flow condition is given by three different values of the congestion increase coefficient ($\alpha = 1, 2$ and 3) resulting in the average travel speed values of 50, 25 and 16.6 km/h.

The results are presented in Table 4 in terms of increase factor of the number of tours needed, compared to the no-variability scenario (i.e. $v = 0$). For example, by setting $\alpha = 2$, $v = 0.2$ and $pw = 8h$ the number of 5-stop tours needed is 1.071 times higher than the number of the same type of tours needed when travel time variability is equal to 0; if, in addition, the tour duration constraint decreases from $pw = 8h$ to $pw = 6h$, the number of 5-stop tours needed increases by a coefficient of 1.439.

Table 4. Increase factors of the number of tours needed

		$pw = 8h$	$pw = 6h$	$pw = 4h$
$\alpha = 1$				
$v = 0.2$	2-stop tours	1.028	1.373	2.064
	5-stop tours	1.034	1.383	2.088
	8-stop tours	1.069	1.433	2.178
$v = 0.4$	2-stop tours	1.059	1.403	2.078
	5-stop tours	1.071	1.425	2.128
	8-stop tours	1.149	1.536	2.313
$\alpha = 2$				
$v = 0.2$	2-stop tours	1.059	1.416	2.134
	5-stop tours	1.071	1.439	2.188
	8-stop tours	1.152	1.557	2.393
$v = 0.4$	2-stop tours	1.127	1.484	2.166
	5-stop tours	1.158	1.535	2.280
	8-stop tours	1.362	1.827	2.775
$\alpha = 3$				
$v = 0.2$	2-stop tours	1.096	1.467	2.218
	5-stop tours	1.117	1.506	2.308
	8-stop tours	1.258	1.712	2.681
$v = 0.4$	2-stop tours	1.214	1.582	2.272
	5-stop tours	1.266	1.674	2.469
	8-stop tours	1.694	2.286	3.513

As expected, the time – sensitivity of the delivery processes is higher for tours reaching more customers per route, since travel time standard deviation grows with the number of stops per tour and affects the right-hand term of expression (5) along with the increase in travel time variability (Fig.6).

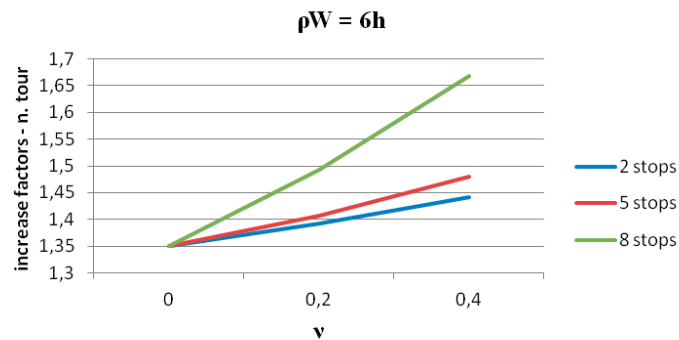


Fig.6. Increase factors variation

More specifically, when comparing delivery processes with 2-stop and 8-stop tours and assuming a constant value both for the travel speed ($\alpha = 2$) and for tour maximum duration ($\rho w = 6$ hours), it is possible to observe a 10% difference in the amount of tours when $v = 0.2$, and a even higher value (more than 22%) when $v = 0.4$.

Focusing on the impacts of the tour duration constraints on the delivery process efficiency, a last finding from the sensitivity analysis can be highlighted. If the following is assumed:

- The impact due to congestion, hypothesizing for each tour an average speed of a 25 km/h ($\alpha = 2.0$) and a coefficient of variation of driving times (v) of 0.2 (according to what observed in the case study);
- The effect due to the concurrency of the temporal constraints affecting the tours maximum travel times along with the requirement of favoured time slots, hypothesizing a comparison between two options: a) deliveries can take place within a 8-hour working shift ($\rho w = 8h$); b) deliveries can take place within a 6-hour working shift ($\rho w = 6h$);

then, it is possible to obtain the increase factors of the number of tours, travelled km and driving times comparing two scenarios dealing with the tour duration constraint, which decrease from 8 to 6 hours.

Table 5. Increase factors of the number of tours needed, distance travelled and driving time

		Tours	Travelled km	Driving time
$\rho w = 6h$	2-stop tours	1.337	1.079	2.160
	5-stop tours	1.343	1.081	2.164
$\rho w = 8h$	8-stop tours	1.351	1.085	2.170

As the temporal constraint (ρw) becomes stricter, then operations are planned to have more travels, although shorter, in order to comply with such temporal constraint; moreover, since the UDC is very close to the area where the majority of deliveries takes place, to an increase of the amount of tours does not correspond a marked increase of connecting distances (i.e., the distance between the UDC and respectively the first and last customers

to serve in each tour). As a consequence, the amount of travelled km increases according to coefficients always minor than those of the number of tours.

On the contrary, driving time sensitivity, if compared to the other two terms, is higher, especially when congestion increases (thus assuming $\alpha = 2$ and $\nu = 0.2$), because speed progressively decreases and the compliance of the temporal constraint calls for tours with a higher amount of travelled km per single customer, with no variation of the replenishment times.

As a result, for a given set of customers' requests, the multiplicative impact of traffic congestion on the road network ($\alpha = 2.0$; $\nu = 0.2$) and the tour duration constraints, result into a general increase of number of tours needed (+ 34,3%) and total distance travelled (+ 9%).

6. Conclusions

The Parma case study allowed to demonstrate the strict relationship existing between the efficiency of the distribution process originated from the local UDC and the size of the area to serve. More specifically, when such an area corresponds to the city center, tours are affected by endogenous and exogenous constraints which prevent operators from optimizing aspects such as occupancy and routes. If Classes I and III are compared, this becomes evident when the effects of these constraints on tours efficiency simultaneously occur:

- the reduction of the occupancy rate up to 50%;
- the 100% (or higher) increase of the direct deliveries;
- the 40% increase of the empty tours.

If the focus is specifically on Urban Tours (Class I), to these a 35% reduction of the average speed must be added and the high variability of such parameter due to the built environment features (narrow carriageways, poor on-street parking availability, high density of intersections) has to be considered. Moreover, their planning is markedly affected by the end-consumers' requirement to have deliveries at given time windows: 75% of end-consumers located in the city center receive goods either in the morning or in the afternoon time slot.

The modeling approach applied demonstrated how the effect due to the simultaneous occurrence of temporal constraints and congestion forces operators to re-plan deliveries in order to have higher amounts of tours but shorter; this by increasing not only the driving time but also the travelled km. Such an effect increases according to the tours "complexity" (increasing number of stops and trips) and, unlike what usually reported in the scientific literature, this is also valid when the distance between the UDC and the area to serve is rather modest, as the case of Parma demonstrated. This also suggests that application of the modeling approach to a city with a valuable built environment, such as that of Parma, can be considered as a step forward compared to those examples applied to less complex urban patterns or where the travelled km parameter becomes dominant in the overall assessment of operations.

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